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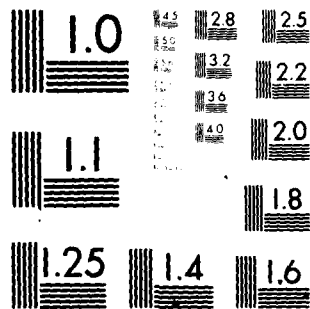
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1.25   1.4   1.6

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MICROCOPY RESOLUTION TEST CHART

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Size of the X-Ray Kernel of the Large
1979 August 20 Solar Flare

Prepared by
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28 November 1980

Interim Report

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This interim report was submitted by The Aerospace Corporation, El Segundo, CA 90245, under Contract No. F04701-80-C-0081 with the Space Division, Deputy for Technology, P. O. Box 92960, Worldway Postal Center, Los Angeles, CA 90009. It was reviewed and approved for The Aerospace Corporation by G. A. Paulikas, Director, Space Sciences Laboratory. Lieutenant James C. Garcia, SD/YLXT, was the project officer for Mission-Oriented Investigation and Experimentation (MOIE) Programs.
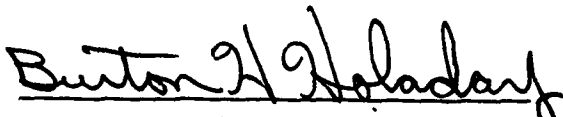
This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusion. It is published only for the exchange and stimulation of ideas.

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(19) REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
SD-TR-80-82	AD-A093 764	

4. TITLE (and Subtitle)	5. TYPE OF REPORT & PERIOD COVERED
SIZE OF THE X-RAY KERNEL OF THE LARGE 1979 AUGUST 20 SOLAR FLARE	Interim
	6. PERFORMING ORG. REPORT NUMBER
	TR-0081(6960-01)-1

7. AUTHOR(s)	8. CONTRACT OR GRANT NUMBER(s)
Peter B. Landecker and David L. McKenzie	F04701-80-C-0081

9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
The Aerospace Corporation El Segundo, Calif. 90245	

11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE
Space Division	28 November 1980
Air Force Systems Command	13. NUMBER OF PAGES
Los Angeles, Calif. 90009	22

14. MONITORING AGENCY NAME & ADDRESS(If different from Controlling Office)	15. SECURITY CLASS. (of this report)
	Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Sun: Corona
Sun: Flares
Sun: Spectroheliograms
Sun: X-rays

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

At the time of the intense Class X5 solar flare on 1979 August 20, monochromatic small raster maps near 7 Å were recorded of the flaring active region with 20" resolution (FWHM) by the SOLEX Solar X-Ray Spectrometer/Spectroheliograph. From these maps, the spatial extent of the x-ray kernel during the rise of this flare at about 0912 UT was determined to be less than 28". The electron density in the hot flare plasma was estimated to be above 10^{12} cm^{-3}. This is the first soft x-ray measurement of the angular size of such an intense flare.

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ACKNOWLEDGMENTS

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I. INTRODUCTION

The Aerospace Corporation solar x-ray spectrometer/spectro-
heliograph experiment on the U. S. Air Force Space Test Program
P78-1 satellite was launched on 1979 February 24. The satellite,
built by the Ball Corporation, provides an accurate solar pointing
platform for this payload.

The SOLEX A (SOLEX = Solar X-Ray) spectrometer has a 20"
FWHM (full width at half maximum) multigrid collimator, an ADP
(Ammonium Dihydrogen Phosphate) or RAP (Rubidium Acid Phthalate)
high spectral resolution Bragg crystal, and a proportional counter
detector with a 25 μm thick beryllium window. The SOLEX B
spectrometer has a 60" FWHM collimator, an ADP or RAP crystal,
and a CEMA (channel electron multiplier array) detector with a
MgF_2 photocathode. The SOLEX crystals and detectors can be
driven so that either spectrometer exposes ADP to the collimated
solar x-rays while the other exposes RAP. The spacecraft pointing
system can raster the SOLEX collimator over the whole sun or a
5' x 5' region (to build up a monochromatic image of a solar active
region), or it can point the instrument anywhere on the sun so that
spectra of those regions defined by the collimators in the 3-25 Å range
are obtained. The MONEX (Monitor X-Ray) experiment simultaneously
records broadband observations of both hard and soft x-ray emission
from solar flares and active regions in the wavelength range 0.1 -
12 Å (1-120 keV). The MONEX hardware consists of two proportional
counter detectors which view the entire sun. Six channels of pulse
height analysis are employed for each detector. The time resolution
for each of the two MONEX proportional counters (wavelength ranges
0.1 - 1.1 and 0.7 - 12.4 Å) is 32 ms. In addition, the time resolution
for each of the twelve MONEX pulse height channels (six for each
counter) is 1.024 s. The SOLEX and MONEX instruments have been
described by Landecker, McKenzie and Rugge (1979) and Landecker
et al. (1979).

Using the X-ray telescopes aboard NASA/Skylab-ATM, Vorpahl et al. (1975) and Kahler, Krieger and Vaiana (1975) studied the morphology of small solar flares. The structure most often seen by these observers was a linear feature of width 5" - 10" and of length 5" - 2'. The size of a solar flare in x-rays is interesting for the following reason. If the volume V of the kernel and the emission measure $\epsilon = \int N_e^2 \, dV$ are known, then an estimate of the mean electron density N_e in the kernel can be made. These may be the only good density estimates obtainable in high temperature coronal plasmas because other known density sensitive X-ray lines for $T \gtrsim 10^7$ K are only sensitive to very high densities (Mason et al. 1979; Gabriel and Jordan 1969). The largest solar flares observed with spatial resolution aboard NASA Skylab-ATM included the events of 1973 September 7, 1973 July 29, and 1973 June 15. The earliest observations of the September 7 Class X1 flare (x-ray peak flux between 1 and 2×10^{-1} erg cm^{-2} s^{-1} between 1 and 8 Å at earth) began about 10 minutes after flare maximum (Moore et al. 1980). By this time, the flare temperature had decreased to less than 8×10^6 K. The July 29 Class M7 flare (x-ray peak flux between 7 and 8×10^{-2} erg cm^{-2} s^{-1}) feet of the loop were both measured to be 32" x 32" (Moore et al. 1980). The largest solar flare observed with good coverage by the ATM/NRL spectrographs on Skylab was the 1973 June 15 event (Widing 1975). The projected length of the XUV arch for this Class M3 flare was estimated to be 26,000 km or 36".

II. OBSERVATIONS

A Class X5 solar X-ray flare (flux in the 1-8 Å band about 7 times that of the 1973 July 29 flare observed from Skylab) was reported in McMath Region 16239 (N5 E76) on 1979 August 20 starting at 0906 UT, with the flare maximum at about 0923 UT (Solar-Geophysical Data, 1979). The rise of this flare was observed by SOLEX and MONEX.

Near 0912 UT, while the SOLEX B RAP crystal channel was recording four successive monochromatic 5' x 5' raster maps at 15.012 Å (Fe XVII $2p^6 \, ^1S_0 - 2p^5 \, 3d \, ^1P_1$) and 18.969 Å (O VIII $1s \, ^2S_{1/2} - 2p \, ^2P_{1/2, \, 3/2}$), the SOLEX A ADP crystal channel was recording two successive pairs of monochromatic maps in the solar continuum at 6.120 Å and 7.735 Å. A map at each of the two continuum bands (uncorrected for instrument electronic dead time) is shown in Figures 1 and 2. SOLEX A and SOLEX B counting rates are each recorded every 32 ms. During this time, the spacecraft pointing control has scanned through an angle 2.44" in azimuth. Figure 3 shows a plot of the counting rates (corrected for instrument dead time) recorded as the center of the collimator field of view scanned along the horizontal line at -13.95' elevation in Figure 2. The background, about 1.3 counts/32 ms, was negligible compared to the peak counting rate of 613 counts/32 ms. The FWHM of this counting rate profile is 28 ±1". An observed FWHM of 28" might arise, for example, from a cylindrical source (seen end on) of width 28", or a uniform sphere of diameter 33". Statistical uncertainties make it impossible to determine uniquely the source shape. At the time of this observation, the flare flux measured by the GOES 2 satellite was 2×10^{-1} erg cm^{-2} s^{-1} in the 1-8 Å wavelength band. Although the solar X-ray flux tripled between 0910.9 and 0913.0 UT when the kernels in Figures 1 and 2 were recorded, the spatial extent and center of emission did not change significantly.

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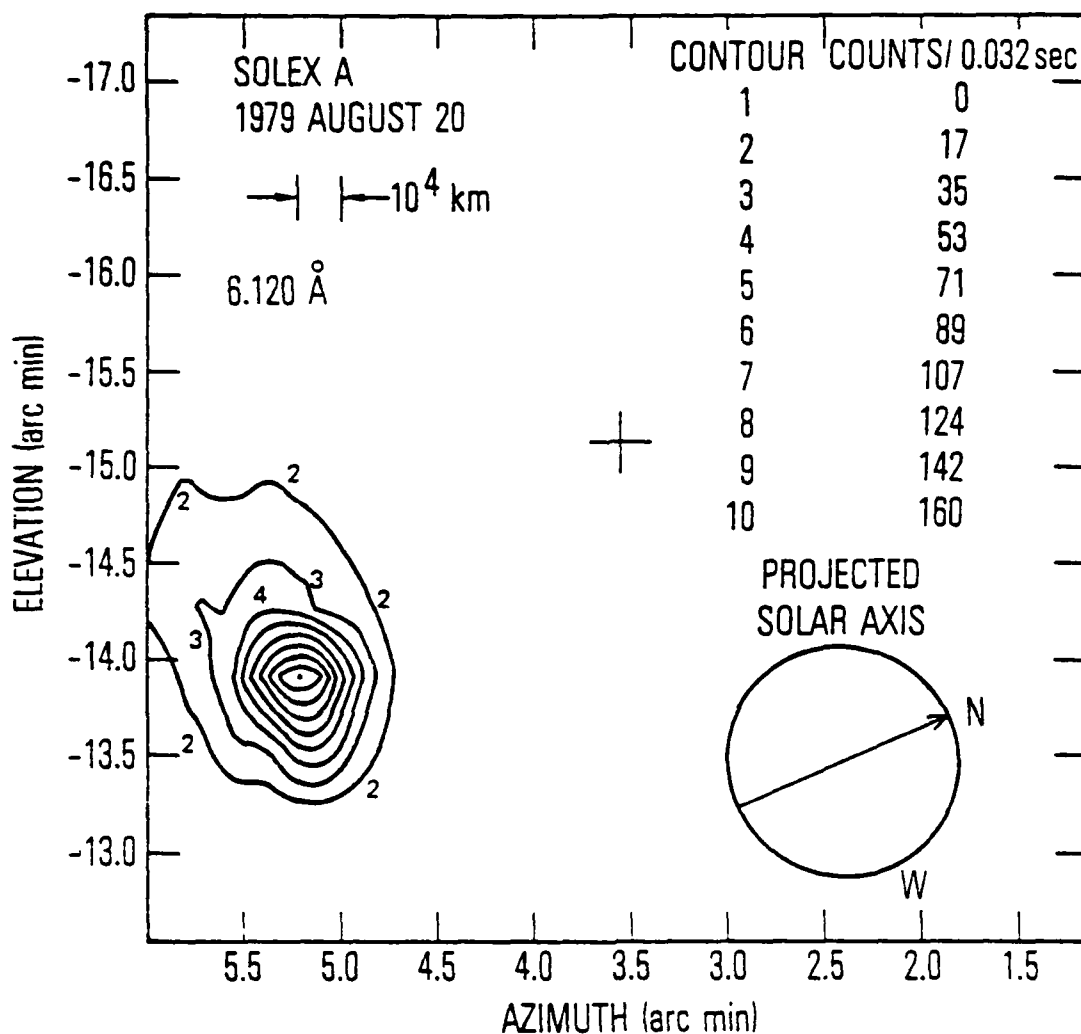
Figure 1. Small Raster Solar Map in 6.120 Å Continuum Made with
SOLEX A 20 arc sec Collimator.

The raster, consisting of 16 horizontal lines, started at
the top of the figure at 9h 10 min 9.4s UT and stopped 61.4 s
later. The raster center (indicated by the cross) is located
at solar latitude N 11.2° and solar longitude E 80.5°, with
the solar north direction indicated. Elevation and azimuth
scales in the figure are with respect to the center of the
solar disk. Intensity levels are in counts per 32 ms.
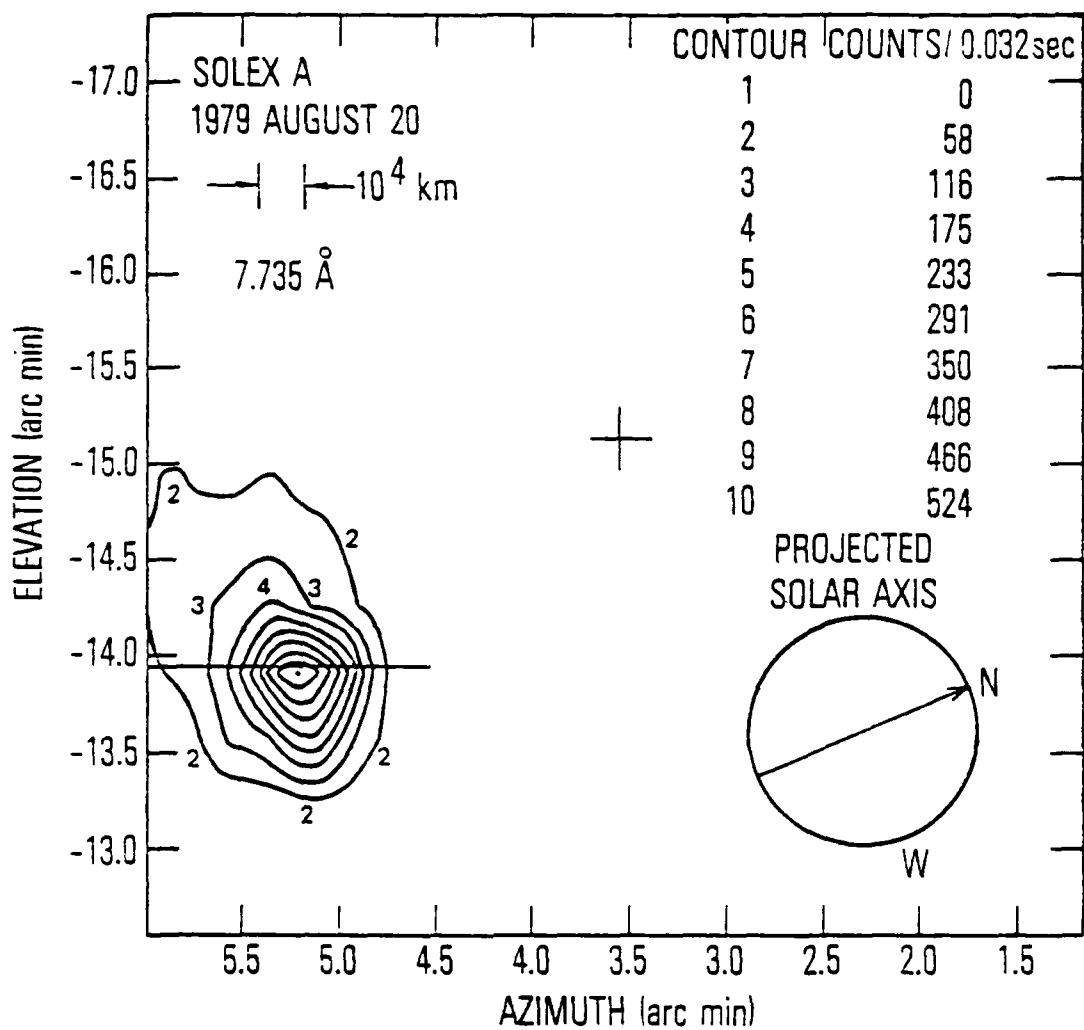
Figure 2.   Small Raster Solar Map in 7. 735 Å Continuum Also Made with
            SOLEX A 20 arc sec Collimator.

        This raster started at 9 h 12 min 12. 3 s UT.   Raster line
number 12, the one with the highest counting rates, is also
shown.   The raster center is the same as in Figure 1.

SOLEX data collection stopped at 0913.8 UT. At that time the
SOLEX detector high voltage supplies were shut off by a MONEX
circuit designed to protect the SOLEX detectors from damage by
high charged particle fluxes. This flare was so intense that the
hard X-ray flux triggered the protection circuit, which was set at
its lowest programmable flux threshold. Thus, although we did not
measure the size of the flare at maximum, it probably was about the
same as it was at the X2 level. Since the flare was at longitude E76,
the image is foreshortened by up to a factor of four and is therefore
more indicative of height than width. However, the scan plotted in
Figure 3 is nearly N-S, and foreshortening is small in this direction.

7.735 Å - SOLEX A - 1979 AUGUST 20

0913.0 UT

COUNTS / 0.032 sec

600

500

400

FWHM • 27.6 arc sec

300

200

100

0

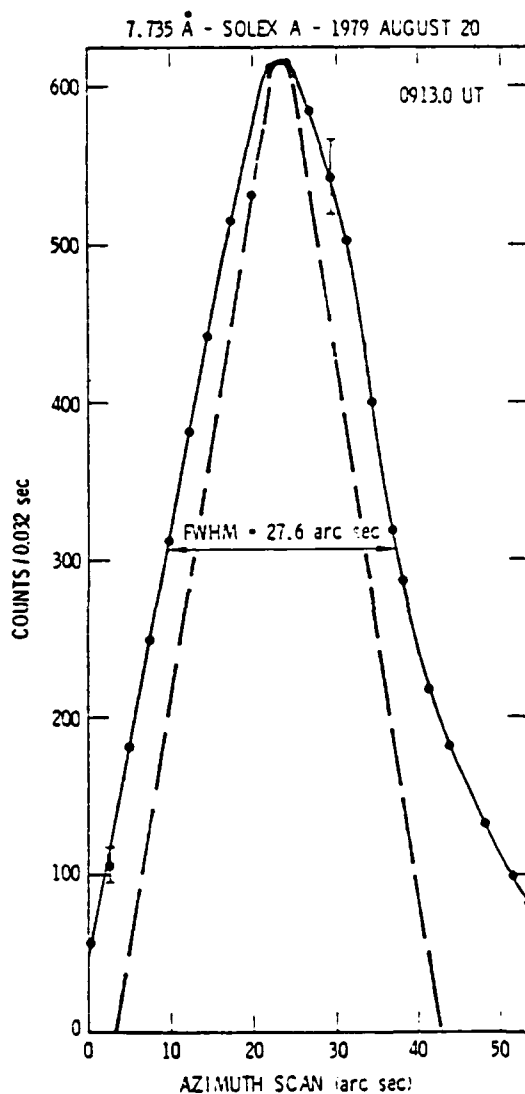0   10   20   30   40   50

AZIMUTH SCAN (arc sec)

Figure 3.   Plot of SOLEX Counting Rates in One Raster Line.

The solid curve is the SOLEX response to the continuum at 7.735 Å for the line in the small raster which gave the highest counting rates. Data were recorded and plotted every 2.44 in. The dashed curve shows the expected collimator response to a point source; the FWHM for this case is 19.3 in.

III. DISCUSSION

This is the first time that the extent of a flare this intense has been measured in the x-ray region. Most solar flare theories predict instabilities in coronal regions much smaller than those reported here, although the size of the regions of heated plasma are clearly much larger than the triggering volumes and may not be spatially coincident with them. Also, since our resolution is only 20", we cannot exclude the possibility that the hot plasma is confined to regions much smaller than the measured 28" overall extent of the kernel.

No known lines contribute significantly to the continuum raster maps shown in Figures 1 and 2. One can see this by considering the Bragg angles of the relevant wavelengths. The HWHM (half width at half maximum) of the 6.646 Å Si XIII $1s^2$ $^1S_0$ - $1s2p$ $^1P_1$ resonance line recorded with the SOLEX A - ADP crystal combination during a large flare on 1979 March 31 was 0.8' (0.014°). The closest line to 6.120 Å (Bragg angle = 35.113°) is the Si XIV Lyman-α line at 6.186 Å (Bragg angle = 35.548°). The continuum at 6.120 Å is therefore about 31 HWHM from this line. Similarly, the closest line to 7.735 Å (Bragg angle = 46.633°) is the weak blend of Al XI and XII lines at 7.761 Å (Bragg angle = 46.838°), located 15 HWHM from it. For Lorentzian line shapes, line emission contributes less than 1% of the flux for the maps under discussion here. From the width of the line at 6.646 Å, it can be inferred that the half intensity bandpass of each continuum map is about 0.004 Å.

The SOLEX maps can be used to obtain an estimate of the electron density, N_e, in the high temperature flare plasma. The maps give only a single measure of the X-ray intensity. Since the intensity is a function of the form $\epsilon \times f(T)$, the emission measure, $\epsilon = \int N_e^2 \, dV$, can be determined if the temperature is known. From the emission measure and knowledge of the flare morphology obtained from the maps,

N_e may be estimated. The derived densities will be lower limits since the plasma may be concentrated in unresolved structures. We obtain the needed temperature estimate from the MONEX Low Energy Monitor (LEM) data shown in Figure 4. The efficiency of the LEM is well known but the energy channel thresholds are somewhat uncertain. However the channel 4/channel 5 boundary is known to be at 5.9 keV from calibrations made at various times during the one year period before launch when the experiment was aboard the spacecraft (there is no inflight LEM calibration source). By using the channel 4/channel 5 counting rate ratio (after background subtraction and deadtime corrections) and model X-ray spectra computed by A. B. C. Walker, Jr. (unpublished), we estimate a temperature of 16×10^6 K throughout the period for which we have SOLEX maps. This is likely to be an overestimate since the high LEM channels respond preferentially to emission from the hottest emitting regions, and the LEM spectrum may be flattened by pulse pileup effects (Datlowe 1975). If the temperature characterizing the continuum at 6.120 and 7.735 Å is lower than 16×10^6 K, the following emission measures will be underestimates.

The fluxes derived from the SOLEX measurements are given in Table 1, where f_c is the collimator transmission averaged over the entire emitting structure when the maximum counting rate in the raster was obtained. The first two measurements were made at 6.120 Å and the last two at 7.735 Å. For a uniform sphere of diameter 33″, centered in the collimator field of view, f_c^{-1} is 2.14. The emission measures derived by using Walker's calculations are given in Table 1. The emission measures are higher than one might expect. This is because the continuum in the 6-8 Å range is emitted by plasma over a wide range of temperatures. For example, at 8 Å, plasmas at temperatures above 7.4×10^6 K emit over half as strongly as a plasma of the same density at 16×10^6 K. Thus the emission

Figure 4.   MONEX Low Energy Monitor Data.
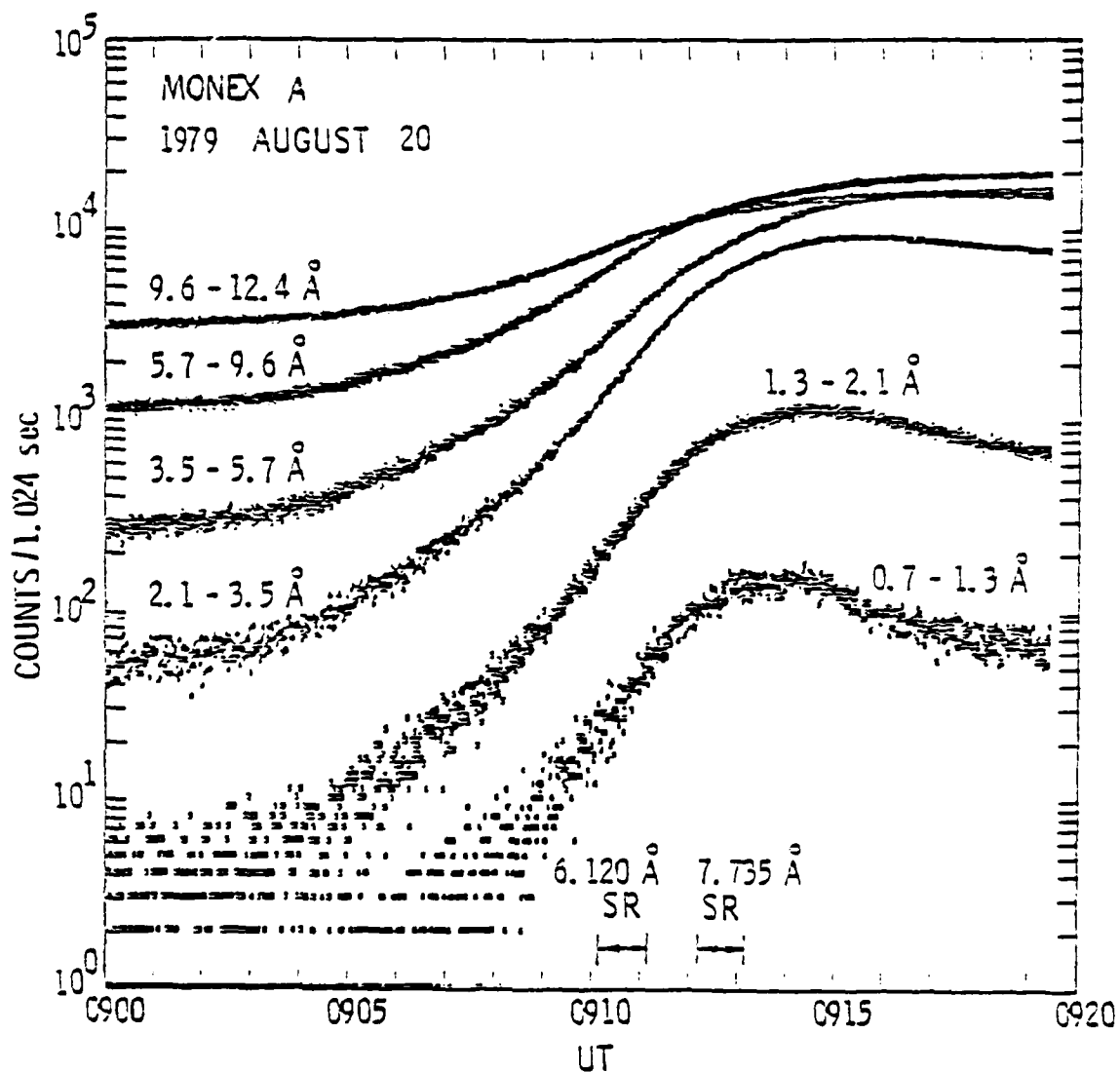
The time intervals when the two SOLEX small rasters were recorded are shown.

Table 1. Derived Flare Parameters

Time (UT)	0909.9	0910.9	0911.9	0913.0
Flux (10^{-2} f_c^{-1} erg cm^{-2}s^{-1}Å^{-1})	1.0	2.2	4.4	7.8
EM (10^{50} cm^{-3})	1.4	3.1	7.3	12.7
N_e (10^{11}cm^{-3})	1.4	2.1	3.2	4.2

measures in Table 1 are for plasma in a broad temperature band. In contrast, emission measure determinations made by using the flux from single spectral lines or shorter wavelength continuum measurements apply only over a relatively narrow temperature range. Therefore the emission measures in the table are not surprisingly high.

Table 1 also gives the electron densities derived from the SOLEX measurements by assuming that the emitting structure is a sphere of diameter 33". The derived densities are somewhat higher than those determined by using the O VII line flux ratio, $1s^2 \, ^1S_0 - 1s2s \, ^3S_1$ to $1s^2 \, ^1S_0 - 1s2p \, ^3P_1$, for flares on 1979 June 10 (McKenzie et al. 1980) and 1979 March 31 (McKenzie and Landecker 1980). For the August 20 flare the temperature of the dense plasma extended well above the 2×10^6 K characteristic of the O VII emission.

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